VOLTAGE DIVIDER CIRCUITS

The circuits used in a television set, missile system and many other electronic devices require several different voltages. Different voltages can be obtained from a single source, such as a battery, by using a voltafe divider. For example, if a small radio needs 3 volts for one circuit, 6 volts for another and 9 volts for still another, all of these voltages could be obtained from one 9 volt battery and a voltage divider. A voltage divider usually is made by connecting two or more resistors in series with a battery or a power supply. At first glance it looks like a simple series circuit but very often others circuitry is connected so that it becomes a series-parallel circuit. The calculations for voltage, current, and resistance that you learned to make in the lessons on series and series-parallel circuits can be used to solve all of the problems presented in this lesson.

The purpose of this lesson is to present the principles and applications of voltage dividers, analyze the operation of different types of voltage dividers, and locate malfunctions that occur in these circuits.

Before proceeding with a description of voltage dividers, a review of the voltage, current, and resistance relationships in series DC circuits will be presented.

The presentation of voltage dividers and the voltage calculations will be handled differently than those of the regular series circuit. The student will develop a sense of accurate estimation, that is, by visual examination of the circuit a ratio can be rationalized to give the voltage drops.

In FIGURE 3, we have a simple two resistor voltage divider. Notice the three outputs A, B, and C. Ground will be the reference point in voltage dividers. This means the BLACK lead of the multi-meter will be connected to point C. The RED lead then can measure the voltage drop at point B, or the applied voltage at point A.

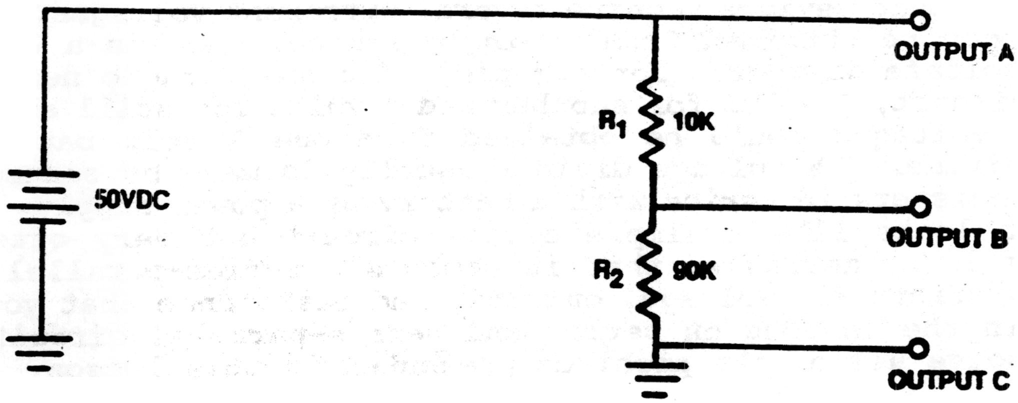

FIGURE 3 (SLIDE EP17AL-S03)

By visualization we can see that the resistance of R_1 and R_2 add up to 90K + 10K or 100K. Now think of the resistances in terms of percentages. 90% + 10% = 100%. Therefore we have 90% of the voltage dropped across R_2 and 10% dropped across R_1. From this 10% of 50V is 5V, and 90% of 50V is 45V.

Traditional calculations may be performed as follows:

Calculate values of resistances, voltages, and currents using Ohm's and Kirchhoff's Laws for a series circuit.

$R_T = R_1 + R_2$

$R_T = 10K + 90K$

$R_T = 100\ K\Omega$

Calculate total current (I_T):

$$I_T = \frac{E_A}{R_T}$$

$$I_T = \frac{50V}{100K}$$

$I_T = .5mA$

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Calculate the voltage dropped (E_R), across each resistor.

$E_{R1} = I_T \times R_1$

$E_{R1} = .5mA \times 10K$

$E_{R1} =$

$E_{R2} = I_T \times R_T$

$E_{R2} = .5mA \times 90K$

$E_{R2} =$

NOTE: Show $E_A = E_{R1} + E_{R2}$

$E_A = 5V + 45V$

$E_A = 50V$

Solve for output A. Voltage at point A is the applied voltage (E_A) minus any voltage dropped, prior to point A.

E point A $= E_A - E_R$

E point A $= 50V - 0V$

E point A $= 50V$

NOTE: Voltage values are with respect to ground.

Solve for output B. Voltage at point B is the applied voltage (E_A) minus any voltage dropped prior to point B.

E point B $= E_A - E_{R1}$

E point B $= 50V - 5V$

E point B $= 45V$

NOTE: Voltage values are with respect to ground.

QUESTION: What would be the voltage value at point B if R_1 were changed to 90K ohms and R2 changed to 10K ohms?

ANSWER: 5VDC

Now let's look at the ratio method in a step by step process, keeping in mind that the voltage drop process across a resistor is directly proportional to the size of the resistor.

Solve for output voltage values using ratio method

NOTE: Refer to FIGURE 3.

Determine the total resistance of the circuit

$R_T = 100K\Omega$

Determine the voltage drops across each resistor by ratio or comparison

$\frac{10K}{100K}$ reduce the fraction to its lowest terms.

$\frac{1}{10}$

1/10 of the applied voltage will be used across R_1 5V is 1/10 of E_A.

$= \frac{90K}{100K}$ reduce the fraction to its lowest terms.

$= \frac{9}{10}$

9/10 of the E_A will be used across R_2 45V is 9/10 of E_A.

Review the above problem and solution. The student <u>must</u> <u>understand</u> the ratio principle.

FIGURE 4 is another example of a voltage divider having a negative supply, that can be calculated using the ratio method.

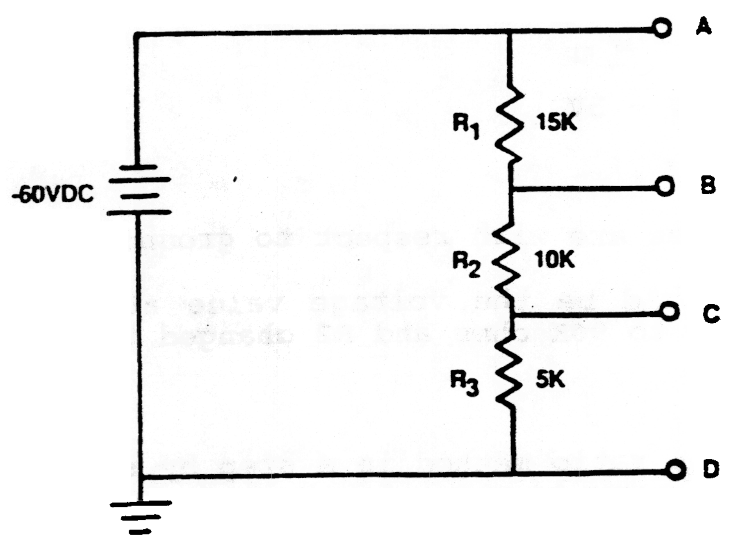

FIGURE 4 (SLIDE EP17AL-S04)

VOLTAGE DIVIDER CIRCUITS

Solve for voltage values at points A, B, and C of FIGURE 4.

There is no difference of potential between the output of the battery and point A. Ouput voltage at point A will be the same as the applied voltage, -60V.

R_1 is one half of the total resistance, thus R_1 will drop one-half of the applied voltage.

$= \frac{15K}{30K}$ reduce fraction to its lowest terms.

$\frac{R_1}{R_.} = \frac{1}{2}$

2 of E_A is -30V

E_{R1} = -30V

R_2 is one-third of the total resistance, R_2 will drop one-third of the applied voltage.

$\frac{R_2}{R_T} = \frac{10K}{30K}$ reduce the fraction to its lowest terms,

$\frac{R_2}{R_T} = \frac{1}{3}$

1/3 of the E_A is -20V

E_{R2} = -20V

R_3 is one-sixth of the total resistance, R_3 will drop one-sixth of the E_A.

$= \frac{5K}{30K}$ reduce fraction to its lowest terms.

$\frac{R_3}{R_T} = \frac{1}{6}$

of E_A is -10V

R_3 = -10V

Determine the output voltage values at each point.

Point A is equal to E_A = -60V

Point B = $E_A - E_{R1}$

Point B = -60V - (30V)

Point B = -30V

Point C = $-E_A - (-E_{R1}$

Point C = -60V - (-30V -

Point C = -60V +50V

Point C = -10

The students must complete 1-4, on the PROBLEM SHEET.

It may be shown in FIGURE 5, that the method of visual inspection may be used to determine how the voltage divides up proportionate to the amount of the resistance.

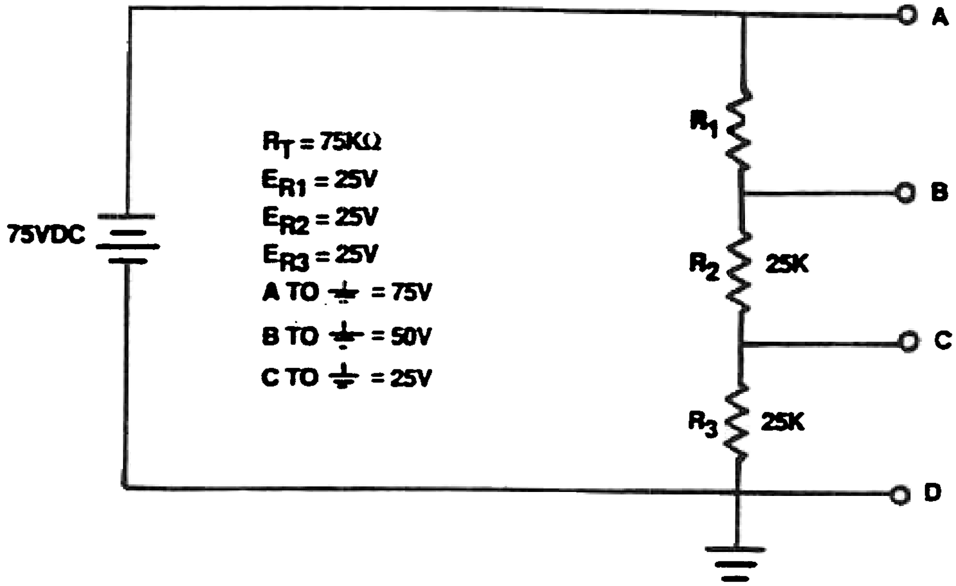

FIGURE 5 (SLIDE EP17AL-S05)

A quick solution would be handled this way:

First, we know the maximum or total voltage is the applied voltage, 75V. Second, note the relative values of each resistor. The value of each resister in this circuit is 25K, giving a total of 75K. Since all resistors are equal, each resistor will have the same amount of voltage dropped, that is, R_1 = 25V, R_2 = 25V and R_3 = 25V.

$E_A = R_1 + R_2 + R_3$

E_A = 25V + 25V +25V

E_A = 75V

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You must always remember to observe the polarity of the voltage, thus ground is the reference point.

As previously stated voltage dividers can be made in many different forms so that both negative and positive voltages may be supplied. See FIGURE 6.

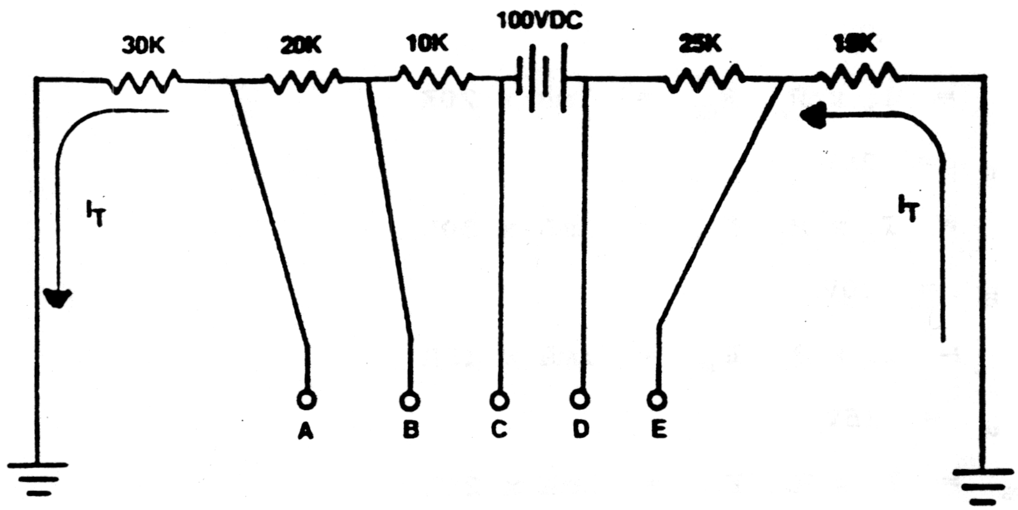

FIGURE 6 (SLIDE EP17AL-S06)

This circuit is a series circuit, it has only one path for current flow and the same current will flow thru all the resistance. Current flow is from the negative terminal of the battery thru R_1, R_2, R_3, R_4 and R_5 to the positive terminal. The voltage is referenced to chassis ground at the junction of R_3 and R_4. At this point the voltage is 0V.

Any output voltage taken between the chassis ground and the negative terminal of the power source will have a negative polarity. Points A, B, and C will be negative.

Any output voltage taken between the chassis ground and the positive terminal of the power source will have a positive polarity. Points D and E will be positive.

To find the correct outputs, solve for values the same as a series circuits.

$$R_T = R_1 + R_2 + R_3 + R_4 + R_5$$

$$R_T = 10K + 20K + 30K + 15K + 25K$$

$$R_T =$$

$$I_T = \frac{E_A}{} = \frac{100V}{100K\Omega}$$

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$I_T = 1mA$

Solve for all voltage drops throughout the circuit.

$= I_T \times R_1$

$1ma \times 10K = 1 \times 10^{-3} \times 10 \times 10^3$

10V

$I_T \times R_2,\ E_{R2} = 1mA \times 20K$

20V

$I_T \times R_3,\ E_{R3} = 1mA \times 30K$

$= 30V$

$= I_T \times R_4,\ E_{R4} = 1mA \times 15K$

15V

$E_{R5} = I_T \times R_5,\ E_{R5} = 1mA \times 25K$

$E_{R5} = 25V$

If <u>this circuit is referenced to ground</u> at the junction of R_3 and R_4, then that point is zero. Add all the voltage drops from the reference point to the negative terminal and this will give the negative output voltage from the power source.

$E_{R1} + E_{R2} + E_{R3}$ = negative voltage from power source
$(-10V) + (-20V) + (-30V) = -60V$

Add all voltage drops from reference to the positive terminal.

$+ E_{R5}$ = positive voltage from power source
$+ 25V = +40V$

Disregarding the polarity, if these output voltages are added they must equal the voltage of the power source.

60V from negative terminal
<u>40V</u> from positive terminal
100V value of power source

Now that the value of the output voltages are known, the different outputs can be found. At the negative terminal, -60V is present. That is also the voltage value at Point C. Point C = -60V

VOLTAGE DIVIDER CIRCUITS

To find Point B, subtract the voltage dropped across R_1 from the voltage value at Point C.

Point B = -60 subtract 10V
Point B = -50V

To find Point A, subtract the voltage dropped across R_2 from the ltage value at Point B.

Point A = -50V subtract 20V
Point A = -30V

Point D has already been solved
Point D = +40V

To find Point E, subtract the voltage dropped across R_5 from the va.ue of Point D.

Point E = +40V - 25V
Point E = +15

Summary of voltage drops.

A = -30V
B = -50V
C = -60V
D = +40V
E = +15V

Voltage dividers that have ouptuts of both polarities can also be lved using the ratio method. This may be shown by using FIGURE 6.

$$\frac{10K}{100K} = \frac{1}{10}$$

= 1/10 of total voltage = 10V

$$= \frac{20K}{100K} = \frac{1}{5}$$

= 1/5 of total voltage = 20V

$$\frac{30K}{100K} = \frac{3}{10}$$

3/10 of total voltage = 30V

$$\frac{15K}{100K} = \frac{3}{20}$$

3/20 of total voltage = 15V

$$\frac{25K}{100K} = \frac{1}{4}$$

1/4 of total voltage = 25V

At this point the purpose of the voltage divider circuit must be taken into consideration. As previously stated, the purpose of the voltage divider is to supply various amounts of voltages to circuits that come after it, and this is demonstrated in FIGURE 7.

The output circuit is connected to points B and C and will be referred to as the load in FIGURE 7.

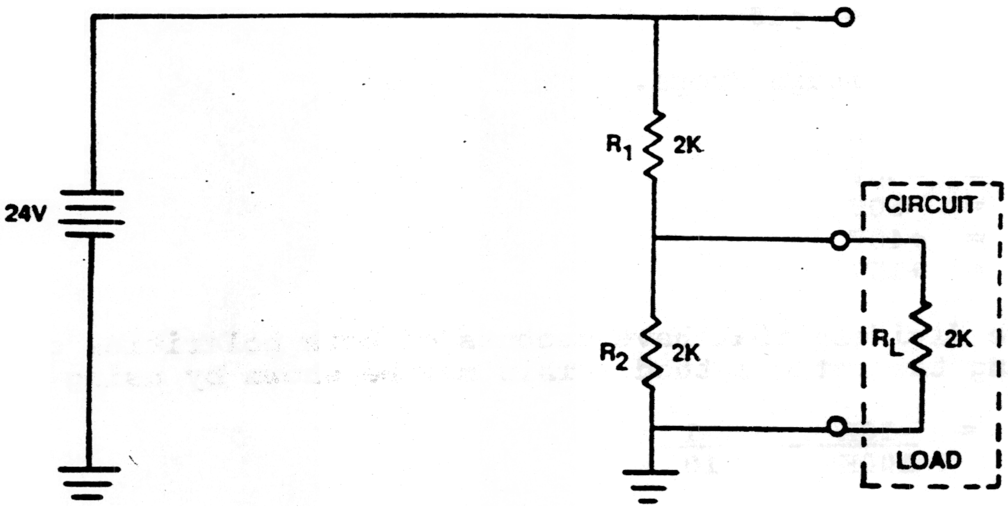

FIGURE 7 (SLIDE EP17AL-S07)

When a load is placed on a voltage divider, it is no longer a series circuit. The circuit is now a series-parallel circuit and all calculations must be based on this type circuit.

If this circuit is analyzed without a load, the total resistance would be 4K ohms, the total current would be 6mA and the output voltage at point B would be 12V.

$$R_T = R_1 + R_2$$
$$R_T = 2K + 2K$$
$$R_T = 4K$$

$$I_T = \frac{E_A}{R_T}$$

$$I_T = \frac{24V}{4K\Omega}$$

I_T

$$E_{R1} = I_T \times R_1$$

$$E_{R1} = 6mA \times 2K$$

$$E_{R1} = 12V$$

If this same circuit is analyzed with a circuit load of 2K ohms, the calculations must be made to include this added resistor.

To establish the total resistance of this circuit, first, calculate the R_{eq} using R_2 and the load resistance which forms a parallel circuit,

$$R_{eq} = \frac{R_2 \times R_L}{R_2 + R_L} = \frac{2K \times 2K}{2K + 2K} = 1K$$

$$\text{Or, } R_{eq} = \frac{R_2}{N} = \frac{2K}{2} = 1K$$

Next add R_1 and the R_{eq} to establish the total resistance.

$$R_T = R_1 + R_{eq} = 2K + 1K = 3K$$

Determine the total circuit current.

$$I_T = \frac{E_A}{R_T} = \frac{24V}{3K} = 8mA$$

The increase in current is due to the parallel circuit formed by the load reistance and R_2, There are now two paths for current flow and at the junction of R_2 and R_L, current must be added.

The voltage dropped across each resistor in the voltage divider has changed because of increased current.

The voltage dropped across R_2 is now higher than the circuit without the load.

$$E_{R1} = I_T \times R_1 = 8mA \times 2K = 16V$$
$$E_{R2} = I_{R2} \times R_2 = 4mA \times 2K = 8V$$

The output voltage to the load at point B is now 8V.

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When a multimeter, TS-352, is placed across a voltage divider, the internal resistance of the multimeter will affect the voltage divider the same way as placing a load on the circuit. Thus it can be seen that the multimeter, TS-352, will affect the output of the voltage divider as shown in FIGURE 8.

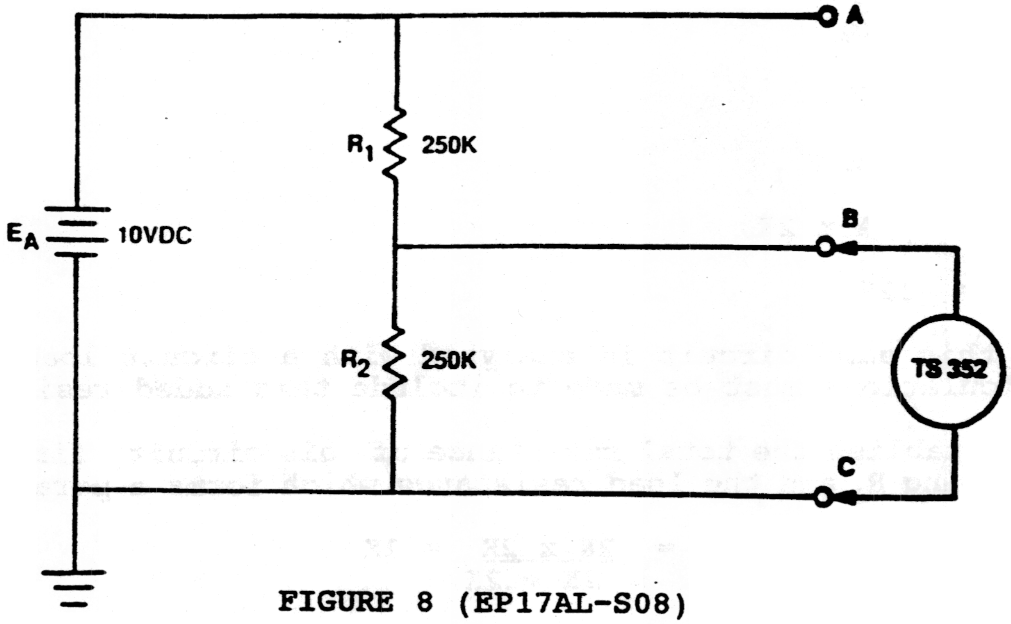

FIGURE 8 (EP17AL-S08)

The TS-352 offers 20,000 ohms of resistance for each one volt selected on the Range jacks. Thus when the 10VDC jack is selected on the TS-352, the total internal resistance of the multimeter is 200K ohms.
(20,000 ohms x 10 = 200K ohms)

When the TS-352 is placed into the circuit of FIGURE 8, the circuit now is a series-parallel circuit. The circuit could be redrawn to show a 200K ohm resistor in parallel with R_2, the 250K ohm resistor. (With the TS-352 set to measure DCV in the 10V jack.)

Calculate values of FIGURE 8 with the TS-352 placed as shown and with the 10V Range selected.

Calculate total resistance:

$$R_{eq} = \frac{R_2 \times R_L}{R_2 + R_L} = \frac{250K \times 200K}{250K + 200K} = \frac{5 \times 10^{10}}{4.5 \times 10^5} = 111.11K$$

$$R_T = R_1 + R_{eq}$$

$$R_T = 250K + 111.11K$$

$$R_T = 361.11K\Omega$$

VOLTAGE DIVIDER CIRCUITS

Calculate total current

$$I_T = \frac{E_A}{R_T} = \frac{10V}{361.11K}$$

I_T = .028mA

Calculate voltage drops across resistances:

E_{R1} = I_T x R_1

.028mA x 250K

= 7V

I_T x Req

.028mA x 111.11K

3V

QUESTION: How much resistance would be offered by the TS-352 if the red test lead was placed in the 250V jack?

ANSWER: 20,000 X 250 = 5 MΩ

When measuring a large voltage with the TS-352, the internal resistance offered by the multimeter will be so loarge that it will not affect the circuit being measured.

(Example: 1000V jack = 20MΩ)

There are two ways to vary the outputs of a voltage divider. By exchanging a fixed resistor with a variable resistor the entire circuit resistance can be changed or a voltage can be taken from any point across the variable resistor. The variable resistors are con-structed identically but when connected in a circuit, it becomes a potentiometer, as shown in FIGURE 9, and a rheostat shown in FIGURE 10.

VOLTAGE DIVIDER CIRCUITS

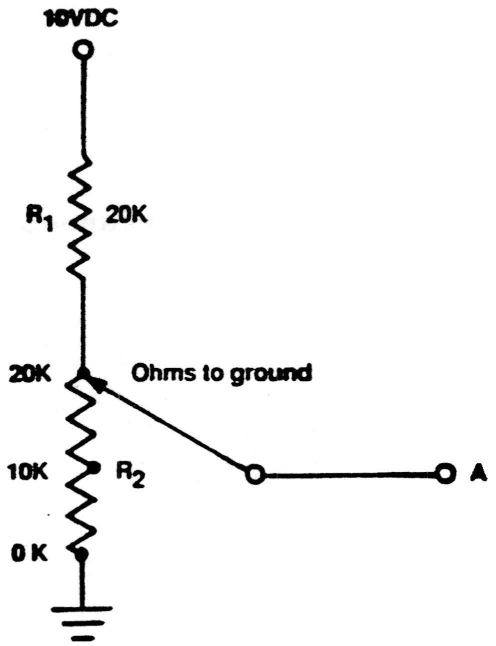

FIGURE 9 (SLIDE EP17AL-S09)

A <u>potentiometer</u> takes the output voltage from any point of the variable resistor. It does not change anything within the basic circuit. The center pin can be moved by adjusting a screw head or by turning a knob. It is connected into the circuit in a way that all current thru the voltage divider will flow thru the total resistance. The voltage dropped by each resistor will remain constant. Each resistor will drop 5V.

With the variable center pin placed at the 20K ohm position the output voltage will be 5V due to the voltage drop across R_1 being 5V. (Output = $E_A - E_{R1}$). When the variable center pin is moved to the 10K ohm position, the output will be 2.5V. This is due to the 10K ohms resistance used to drop voltage before the output is taken off. When the variable center pin is moved to the "0" Ohm position, the output will be zero volts. All the voltage has been dropped across R_1 and R_2. The output taken from this circuit will vary between 0V and 5V.

QUESTION: When the variable center pin is moved from the 10K ohm position to the 20K ohm position, will the output voltage increase or decrease?

ANSWER: Increase.

A <u>rheostat</u> is a variable resistor that will change the total resistance of the circuit when adjusted. A rheostat is connected in the circuit in a manner that will allow the current to by pass some portion of the circuit resistance. If the circuit resistance changes, then the current within the circuit will also change. This will allow the voltage drop across R_1 to change. The rheostat is shown in FIGURE 10.

VOLTAGE DIVIDER CIRCUITS

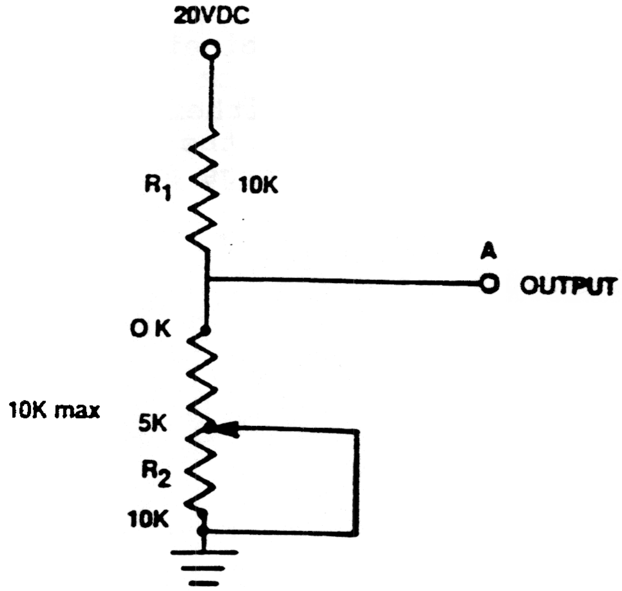

FIGURE 10 (SLIDE EP17AL-S10)

With the variable center pin positioned at the 10K ohm position, the total resistance will be 20K ohms. The current will flow thru the 20K ohms of resistance. Current for this circuit will be 1mA and the output voltage will be 10V.

If the variable center pin is moved to the 5K ohm position, the total resistance will be 15K ohms. This is because current will take the path of least resistance. Current flow will be from ground to the point below R_2 up thru the wiper arma nd enter the resistor (R_2) at the 5K ohm position. The current will then flow thru all 15K ohms of resistance, 5K ohms of R_2 and 10KK ohms of R_1. Since the total resistance decreased the total current will increase to 1.33mA. With the increase of current the voltage dropped across R_1 will increase to 13.33V, leaving an output of 6.67V.

Move the wiper arm to the "0" Ohm position and the output will be zero volts. This happens because the common reference (ground), is now moved to the bottom of R_1, therefore R_2 is shorted by the wiper arm.

QUESTION: Which of the two types of variable resistors will change the total current in the circuit?

ANSWER: Rheostat

QUESTION: What is the major difference between a rheostat and a potentiometer?

ANSWER: A rheostat is connected to the circuit to change the total resistance and current when adjusted. A potentiometer only extracts a voltage from a given point of the circuit.

VOLTAGE DIVIDER CIRCUITS

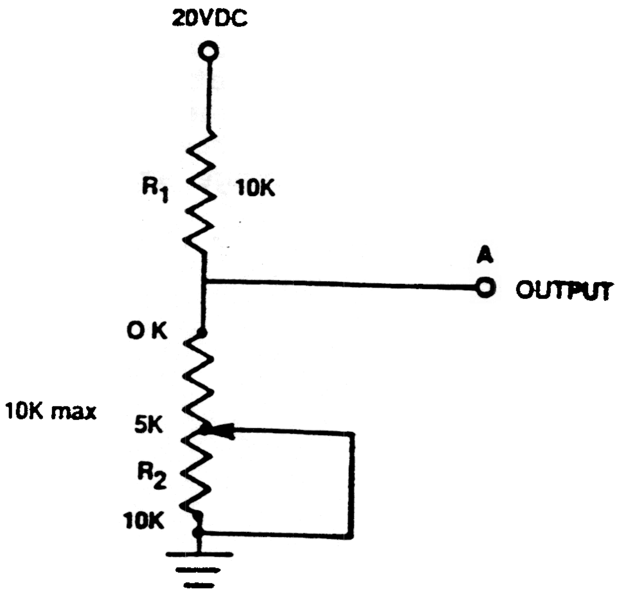

FIGURE 10 (SLIDE EP17AL-S10)

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